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Efficient Linearized Semiconductor Optical Modulators (ELSOM)

(awarded under RFLICS thrust 1)

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Outline

I. Technical overview

II. Coupled quantum well modulators

III. Waveguide engineering for modulators

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ELSOM technical overview

Program purpose is to demonstrate:
broadband (0.2 - 20 GHz)
efficient (V_π goal of 0.5 V)
linearized (goal is 25 dB IP3 improvement vs raised cosine T(V))
semiconductor optical intensity modulators operating in the 1550 nm band

Two complementary technical approaches will be pursued independently:
electronic bandgap engineering using coupled quantum wells (CQW)
photonic bandgap engineering using 1-D and 2-D PBG structures

Two other top-level technical tasks will support above approaches:
iterative development and validation of a modeling tool for CQW design
iterative development of a prototype ELSOM packaging technology

Baseline modulator type is interferometric, since absorption modulators have reduced power handling capability and may be less engineerable
(e.g. want a “brick wall” absorption edge to maximize efficiency, but in practice there is limited control over absorption edge width in a room temperature device)

QCSE electrorefraction is reduced by cancellation in KK integral for Δn

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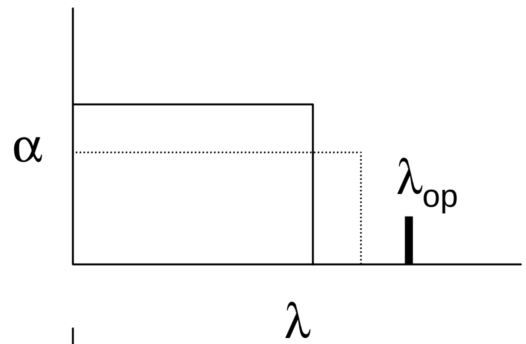
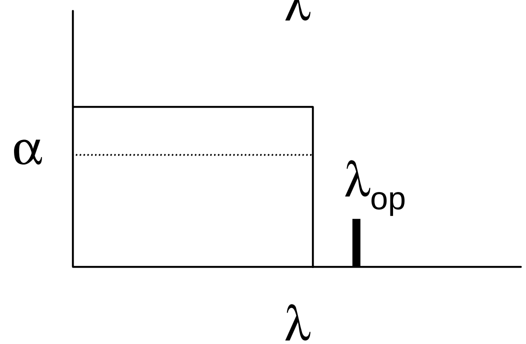
Conventional QCSE



Absorption increases at some wavelengths and decreases at others => Δn at λ_{op} reduced by cancellation

Coupled Quantum Wells (CQW)



Δn at λ_{op} not reduced by cancellation. λ_{op} can be closer to absorption edge

First order CQW design goal is to obtain a significant reduction in absorption strength with zero red shift (even better a blue shift) to eliminate cancellation in Kramers-Kronig (KK) integral for Δn

(In principle, another desirable situation is increased α combined with a red shift, but we expect this to be more difficult to obtain in practice)

Bandgap engineering of coupled quantum wells gives required control over $\alpha(\lambda, V)$

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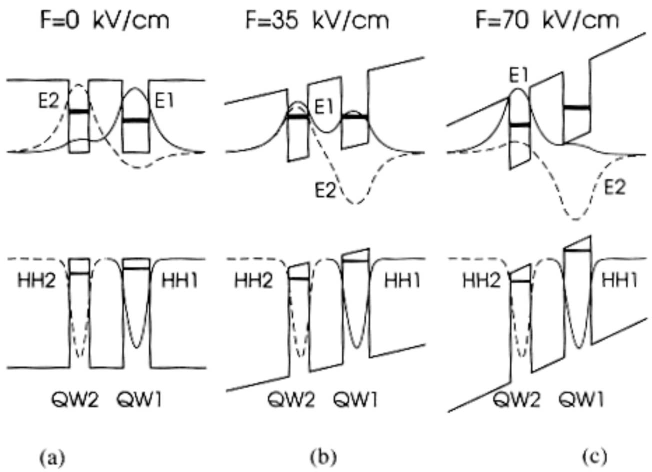

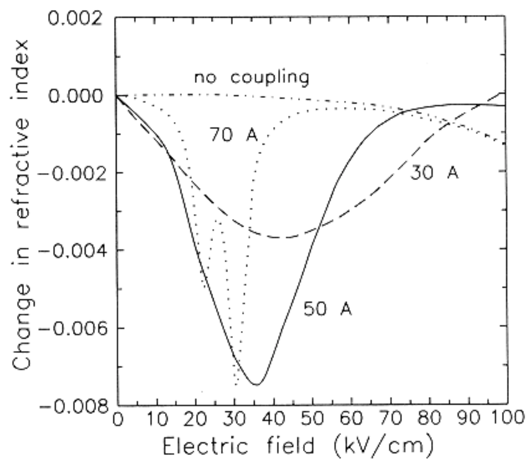

For example, calculations in literature show

F = 0, HH1 to E1 dominates, localized exciton, α large

F = 35 kV/cm, HH1 to E1 and E2 dominate, delocalized exciton, α small

F = 70 kV/cm, HH1 to E2 dominates, localized exciton, α large

QW1 and QW2 are narrow => QCSE red shift is negligible

Plot shows significant enhancement of dn/dE (i.e. efficiency) @ F $\approx$ 35 kV/cm

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Waveguide design can increase dn_e/dE for given dn/dE

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The effective index of a waveguide mode can always be expressed in terms of the modal fields and waveguide structure

For example, one general identity is given by

$$n_e = \frac{c}{2}\frac{\mu_0 \int \mathbf{h}^2(x,y)dA + \varepsilon_0 \int n^2(x,y)\mathbf{e}^2(x,y)dA}{\int \mathbf{e}(x,y)\times\mathbf{h}(x,y)\cdot\hat{\mathbf{z}}\,dA}$$

=> If n(x,y) depends on applied electric field E, and the fields e and h are not significantly changed by the EO perturbation, then dn_e/dE is related to dn/dE by an overlap integral

=> to obtain desired condition dn_e/dE >> dn/dE, must design a waveguide where modal fields are significantly changed by applied electric field

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1D periodic cladding in waveguide gives a promising V_π estimate

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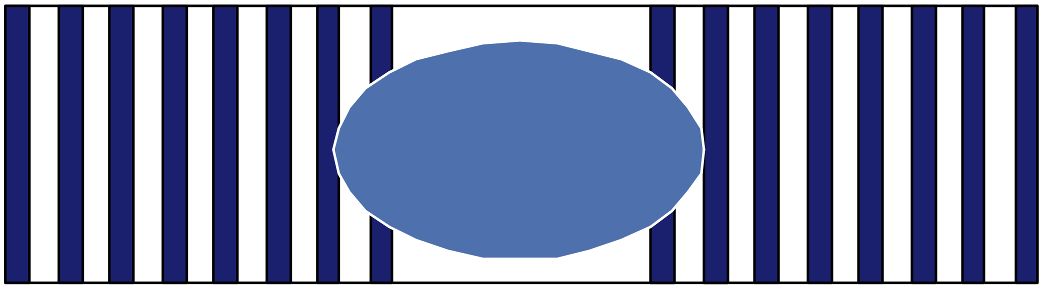
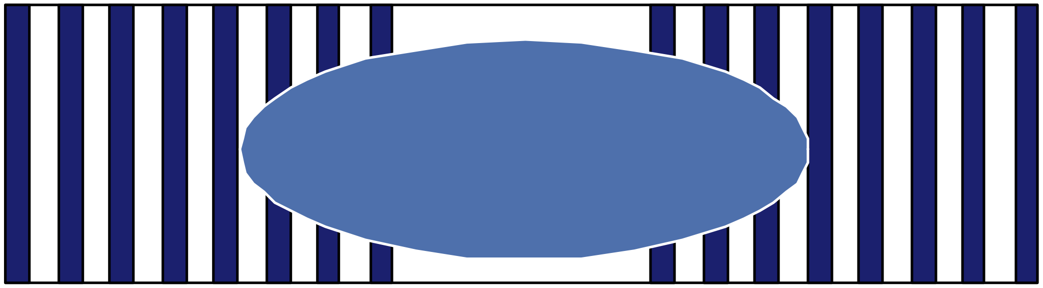


Design so that mode is near edge of cladding stop band

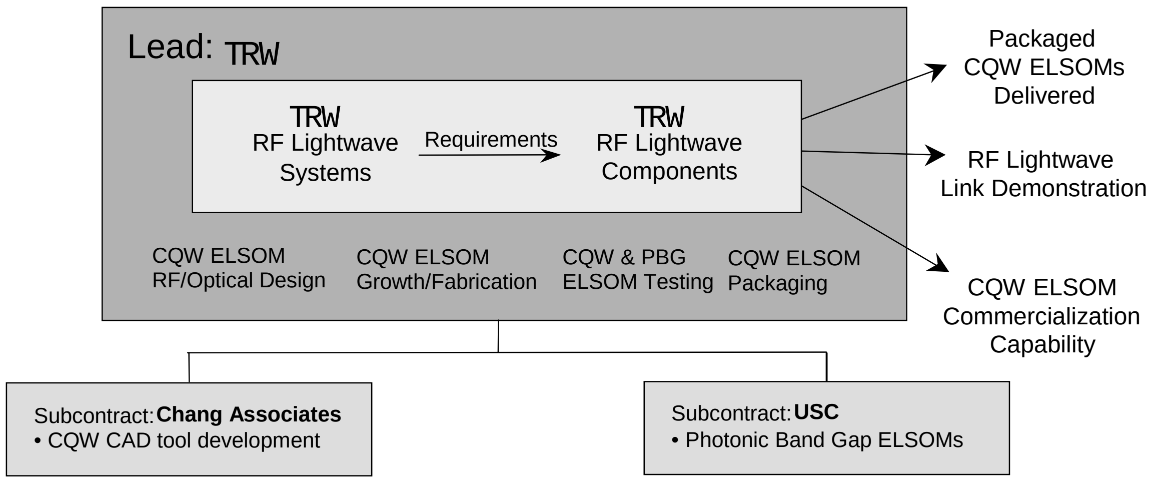


Small index perturbation in cladding will have large effect on modal field
=> large effect on n_e

Estimated V_π is ~0.5 V for a 1 mm long GaAs device that is 1μm thick (i.e. 1D periodic waveguide is lateral instead of vertical)

Thorough waveguide engineering required to realize this performance (e.g. must be low loss, single mode, buildable etc.)

ELSOM organization



USC subcontract to develop/demonstrate application of photonic bandgap engineering to ELSOMs (PI is John O'Brien)

Chang Associates subcontract to develop and refine CQW modeling tool (PI is William Chang)